IEA INTERNATIONAL ENERGY AGENCY

Trends in Photovoltaic Applications in Selected IEA Countries between 1992 and 1999

PVPS

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Report IEA-PVPS T1-08:2000

Cover photographs: Each of the lighting pylons lining the Olympic Boulevard at Australia's Sydney Olympic site carries 6.8 kW_p of PV. Photographs courtesy of Energy Australia.

Contents

This report has been prepared under the supervision of Task 1 by John Knight of Halcrow Gilbert (GBR) on the basis of National Survey reports prepared by Task 1 experts and their assistants (see annex A). The report has been funded by the IEA-PVPS Common Fund and has been approved by the IEA-PVPS Executive Committee.

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Foreword

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD). The IEA carries out a comprehensive programme of energy co-operation among its 23 member countries and with the participation of the European Commission.

The Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R&D agreements within the IEA and was established in 1993. The mission of the Programme is 'to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy source in the near future.' The underlying assumption is that the market for PV systems will gradually expand from the present niche markets of remote applications and consumer products, to the utility market, through building-integrated and other diffused and centralised PV generation systems.

In order to achieve this, the 20 countries participating in the Programme and the European Commission have undertaken a variety of joint research projects in applications of PV power systems. The Programme is organised into nine Tasks. This report has been prepared under Task 1, which facilitates the exchange and dissemination of information arising from the PVPS Programme.

"The International Survey Reports published by the IEA-PVPS agreement have gradually become an important reference document, being a reliable source of useful information in the rapidly growing field of solar PV applications. Although the report can be downloaded from our website (www.iea-pvps.org) we know how much a 'real' document is appreciated by many readers. I trust that this fifth issue will find a large audience, also outside the PV community."

Erik Lysen
Chairman IEA-PVPS Programme

Chapter 1 Introduction

1.1 Survey report scope and objective

As part of the Photovoltaic Power Systems Programme, annual surveys of PV power applications and markets in the 20 participating countries[1] are carried out. The objective of the survey reports is to present and interpret trends in both PV systems and components being used in the PV power systems market, as well as changing applications within that market, in the context of business situations, policies and relevant non-technical factors in the reporting countries. The survey report is not intended to serve as an introduction to PV, nor as a policy document. It is prepared to assist those responsible for developing the business strategies of PV companies and to aid the development of medium term plans for electricity utilities and other providers of energy services. It also provides guidance to government officials responsible for setting energy policy and preparing national energy plans.

This report presents the results of the Fifth International Survey. It provides an overview of PV power systems applications and markets in the reporting countries at the end of 1999 and analyses trends in the implementation of PV power systems between 1992 and 1999.

1.2 Survey method

Data were drawn from national survey reports[2], which were supplied by representatives from each of the participating countries. A list of the national representatives is given in annex A.

The scope of the reports is limited to PV applications with a peak rating of 40 W_p or more. Most national data supplied were accurate to ±10 %, although data on production levels and system prices vary depending on the willingness of the national PV industry to provide data for the survey.

The data were collated and this report prepared by the Technical Writer. The report has been reviewed by the national representatives to ensure the accuracy of the data used and approved by the IEA-PVPS Executive Committee.

1.3 Definitions, symbols and abbreviations

For the purposes of this report, the following definitions apply:

Demonstration programme: a programme to demonstrate the operation of PV systems to the general public and potential users/owners.

Market deployment initiatives: activities to encourage the market deployment of PV through the use of market instruments such as green pricing, rate based incentives etc. They may be implemented by government, the financing industry, utilities etc.

MUSD: million U.S. Dollars (see USD).

PV system: a system including photovoltaic modules, inverters, batteries and all associated installation and control components. When calculating installed photovoltaic capacity only systems with a capacity of 40 W_p or more have been included.

USD: U.S. Dollars: the currency used throughout the report. Exchange rates are given in annex B.

Watt peak (W_p): the peak power of a PV module or system under standard test conditions of 1 000 Wm^{-2} irradiance, 25 ºC junction temperature and solar reference spectrum AM 1.5.

[1] Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), the United Kingdom (GBR), the United States of America (USA)

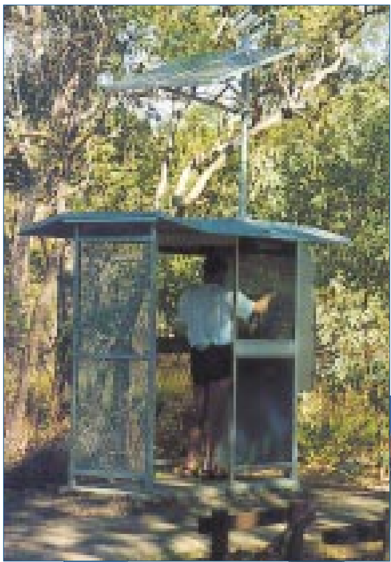
[2] A survey report was not available from Portugal and so 1997 data were used where appropriate.

Chapter 2 Implementation of PV systems

2.1 Applications for photovoltaics

For the purposes of this survey, three primary applications for PV power systems were identified.

Off-grid installations were the first economic application for terrestrial PV systems. Off-grid systems provide electricity to isolated households in remote areas and have been installed worldwide but particularly in developing countries, where they are often the most appropriate technology to meet the energy demands of rural communities. Off-grid PV systems generally offer an economic alternative to extension of the utility grid at distances of more than 1 or 2 kilometres from existing lines. Off-grid PV systems are also used to provide electricity for a wide range of equipment, such as telecommunications, water pumps, vaccine refrigeration, safety, control and protection devices and navigational aids. In these applications small amounts of power have a high value and PV is cost competitive.



On-grid distributed PV systems are a relatively recent application where a PV system is installed to supply power to a building or other load that is connected to the utility grid. The systems usually feed electricity back into the utility grid when electricity generated exceeds the building loads. These systems are increasingly being integrated into the built environment and are likely in the future to become commonplace. They are used to supply electricity to residential homes, commercial and industrial buildings, and are typically between 1 kW_p and 50 kW_p in size. There are a number of perceived advantages for these systems: distribution losses are reduced because the systems are installed at the point of use, no extra land is required for the PV systems, costs for mounting systems can be reduced, and the PV array itself can be used as a cladding or roofing material. Compared to an off-grid system costs are saved because energy storage is not required which also improves system efficiency.

On-grid centralised systems have been installed for two main purposes: as an alternative to centralised power generation from fossil fuels or nuclear, or for strengthening of the utility distribution-grid. Utilities in a number of countries were interested in investigating the feasibility of these types of power plants. Demonstration plants have been set up in Germany, Italy, Japan, Spain, Switzerland and the USA, generating reliable power for utility grids and providing experience in the construction, operation and performance of such systems. However, utility interest is now tending to focus on distributed PV plants and few centralised plants have been started since 1996.

2.2 Total photovoltaic power installed

516 MW_p of PV power had been installed in the reporting countries by the end of 1999. The increase in installed capacity between 1992 and 1999 is shown in Figure 2.1, broken down into the three primary applications for PV power systems. Although the worldwide installed power will be significantly higher than this, it is indicative of the global trend.

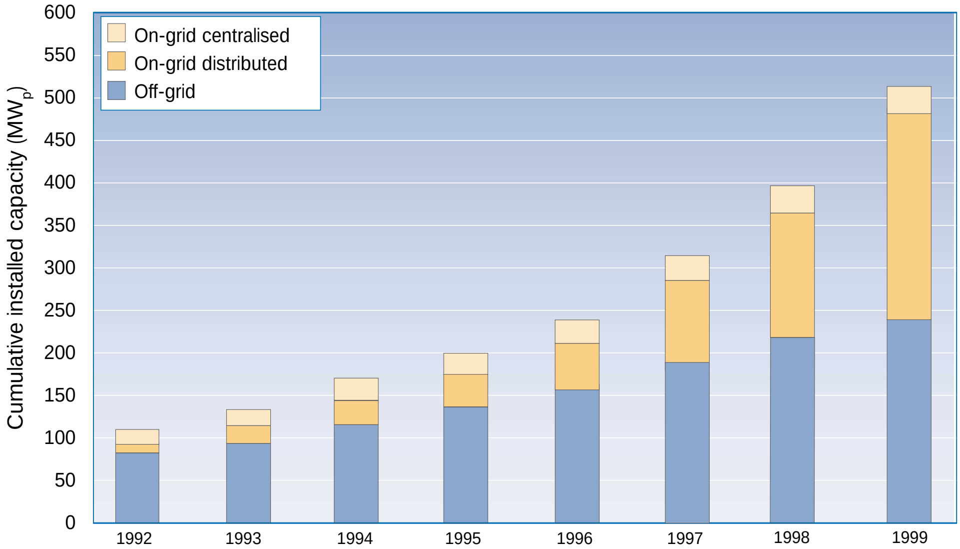


Figure 2.1 - Cumulative installed PV power by application area in the reporting countries

Between 1992 and 1998 the total installed capacity grew by 20-28 % per annum. This increased to 31 % between 1998 and 1999. However with reference to Tables 2.1 and 2.2 it can be seen that this rise is due singularly to the dramatic increase in PV systems in Japan. If Japan is omitted then the cumulative installed capacity in the reporting countries between 1998 and 1999 increased by 19 % (similar to the previous year). Indeed it can be seen from Table 2.1 that of the 121 MW_p installed during 1999 60 % was installed in Japan alone. Collectively Japan, the USA and Germany accounted for 87 % of the 121 MW_p installed in 1999 although Switzerland remains the country with the highest installed power per capita.

Figure 2.1 shows that traditionally most PV systems were for off-grid applications. This is still true in the majority of the reporting countries and in Australia, Canada, Finland, France, Israel, Korea, Mexico, Norway, Portugal and Sweden over 90 % of the total installed capacity is off-grid. This encompasses a wide range of applications: in Canada, Finland, Norway and Sweden, the majority of off-grid PV systems are used for seasonal/recreational buildings and remote cabins. In France, Israel[3] and Mexico, PV is used as a strategy for rural electrification. In Australia, Korea and Japan most off-grid systems are non-domestic - providing power for pumps, agriculture, traffic signals and, in particular, telecommunications. For remote areas PV provides a commercial alternative to diesel and central grid supplies.

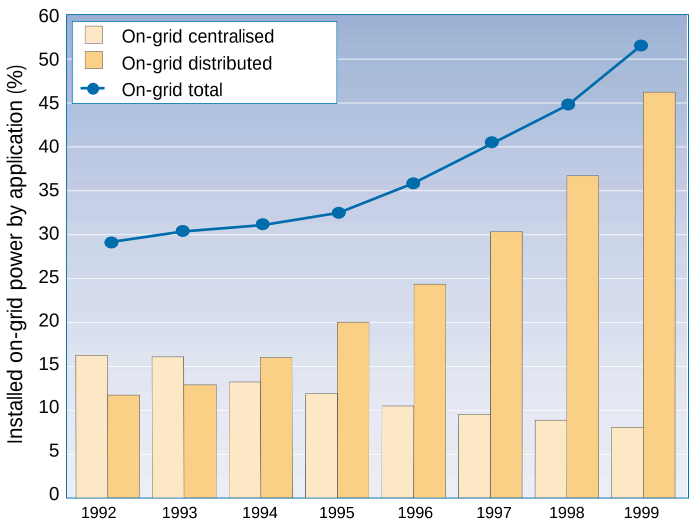


Figure 2.2 - Percentage of grid-connected PV power in the reporting countries (centralised and distributed)

[3] *This mainly concerns PV applications in the Palestinian Authority*

However the overall trend, as shown in Figure 2.1 and more explicitly in Figure 2.2, is a rapid increase in the proportion of PV power that is grid-connected. In 1992 only 29 % of the installed capacity was connected to the grid, by the end of 1999 this had reached 53 %. This is due almost entirely to a proliferation of on-grid distributed systems. The only country to install a noteworthy quantity of on-grid centralised PV in 1999 was Germany (1.5 MW_p).

The rapid rise in on-grid distributed applications is driven mainly by the large, government-subsidised programmes in Japan, Germany, the USA, the Netherlands and Switzerland, which focus on PV in the urban environment. Although not significant in absolute terms it is worth noting that the on-grid distributed market is actually expanding most rapidly in Denmark and the UK (countries with a relatively small PV market) and in countries such as Australia and France where, traditionally, PV has been used for off-grid applications.

2.3 Major projects, demonstration and field test programmes

Although off-grid PV applications account for the majority of the total installed power in many countries, there are few major projects or demonstration programmes. This is because the off-grid market is relatively well established in the reporting countries and, by its nature, installed systems tend to be small and isolated.

One of the largest programmes promoting off-grid domestic PV installations is in France. In 1993 ADEME and the French electricity company EDF signed an agreement to promote the use of PV (and wind) for isolated houses where grid extension is more expensive than using renewable energy. The FACE

Table 2.1: Cumulative installed PV power as of the end of 1999

Country	Off-grid (kW_p)	On-grid distributed (kW_p)	On-grid centralised (kW_p)	**Total (kW_p)**	Total installed per capita (W_p/capita)	Power installed in 1999 (kW_p)
AUS	23 180	1 490	650	**25 320**	1.34	2 800
AUT	1 413	2 119	140	**3 672**	0.45	811
CAN	5 529	287	10	**5 826**	0.19	1 356
CHE	2 500	9 420	1 480	**13 400**	1.89	1 900
DNK	190	880	0	**1 070**	0.20	565
DEU	11 500	49 100	8 900	**69 500**	0.85	15 600
ESP[1]	7 000	600	1 480	**9 080**	0.23	1 080
FIN	2 255	17	30	**2 302**	0.45	132
FRA	8 772	349	0	**9 121**	0.16	1 490
GBR	395	736	0	**1 131**	0.02	441
ISR	381	6	14	**401**	0.07	93
ITA	10 860	905	6 710	**18 475**	0.32	795
JPN	56 900	145 500	2 900	**205 300**	1.63	71 900
KOR	3 171	288	0	**3 459**	0.07	477
MEX	12 920	2	0	**12 922**	0.13	900
NLD	3 886	5 309	0	**9 195**	0.59	2 715
NOR	5 670	0	0	**5 670**	1.28	320
PRT[2]	486	17	0	**503**	0.05	0
SWE	2 460	124	0	**2 584**	0.29	214
USA	84 200	21 100	12 000	**117 300**	0.43	17 200
Totals	**243 668**	**238 249**	**34 314**	**516 231**	**0.54**	**120 789**

[1] *Approximate*

[2] *No data available for 1999 or 1998, installed capacity as at 31 December 1997*

Table 2.2: Cumulative installed PV power (kW_p): historical perspective

Country	1992	1993	1994	1995	1996	1997	1998	1999
AUS	7 300	8 900	10 700	12 700	15 700	18 700	22 520	25 320
AUT	524	768	1 062	1 360	1 739	2 208	2 861	3 672
CAN	960	1 240	1 510	1 860	2 560	3 380	4 470	5 826
CHE	4 710	5 775	6 692	7 483	8 392	9 724	11 500	13 400
DNK[1]	0	85	100	140	245	422	505	1 070
DEU	5 619	8 900	12 440	17 790	27 890	41 890	53 900	69 500
ESP[2]	3 950	4 649	5 660	6 547	6 933	7 100	8 000	9 080
FIN	914	1 034	1 156	1 288	1 511	2 042	2 170	2 302
FRA[3]	1 751	2 051	2 437	2 940	4 392	6 118	7 631	9 121
GBR	173	266	338	368	423	589	690	1 131
ISR	100	120	150	180	210	265	308	401
ITA	8 480	12 080	14 090	15 795	16 008	16 709	17 680	18 475
JPN	19 000	24 270	31 240	43 380	59 640	91 300	133 400	205 300
KOR	1 471	1 631	1 681	1 769	2 113	2 475	2 982	3 459
MEX[3]	5 400	7 100	8 820	9 220	10 020	11 022	12 022	12 922
NLD	1 270	1 641	1 963	2 400	3 257	4 036	6 480	9 195
NOR[3]	3 750	4 050	4 350	4 600	4 850	5 100	5 350	5 670
PRT[4]	47	97	135	204	289	503	503	503
SWE	800	1 040	1 337	1 620	1 849	2 127	2 370	2 584
USA	43 500	50 300	57 800	66 800	77 200	88 200	100 100	117 300
Totals	**109 719**	**135 997**	**163 661**	**198 444**	**245 221**	**313 910**	**395 442**	**516 231**

[1] *No data available for 1992*

[2] *Approximate capacity for 1999*

[3] *Revision to data in 4th International Survey Report*

[4] *No data available for 1999 or 1998, installed capacity as at 31 December 1997*

fund (Fonds d'Amortissement des Charges d'Electrification), usually devoted to grid extension/reinforcement in rural areas, was used to support off-grid PV. Between 1995 and 1999, 871 kW_p (1 156 systems) were installed under this programme. The 5 year programme avoided 105 MUSD of line extensions.

In Australia, state government support is provided for conversion of remote area power supplies from diesel to renewable energy sources. In two states, Queensland and Western Australia, about 130 kW_p of PV were installed under these schemes in1999.

A number of the recent major off-grid projects are PV hybrid systems. For example, the Wilpena Pound Solar Power Station in Australia (a 100 kW_p ground-mounted array in configuration with 440 kW diesel and 400 kWh battery storage), the San Juanico plant in Mexico (PV/wind/diesel generator) and a PV/diesel hybrid system installed for a mountain house in Korea. Other projects seek to demonstrate the use of PV in particular locations or applications. The Nunavut Arctic College, Canada, demonstrates that PV can operate reliably at high latitudes and was the first distributed PV system linked to a remote diesel grid.

In contrast to off-grid applications, a number of countries have initiated very large programmes to promote on-grid PV, in particular Japan, Germany and the USA. These are mainly market introduction programmes, aiming to reduce costs through the sheer scale of the programme and to raise public awareness.

In Japan there are several large PV demonstration programmes. The objective of the 'Residential PV System Dissemination Programme' is to subsidise the installation costs for individuals on the condition that they perceive the significance of PV and provide the operational data of their system. Between 1994 and 1998, PV systems were installed on 15 596 houses with a further 17 396 houses accepted in 1999 under this programme. When these are installed, the total capacity will be 121.2 MW_p. Residential PV systems are typically 3-5 kW_p and account for over 80 % of the demand for PV in Japan. The PV Field Test for Public Facilities was completed in 1997 and resulted in a total of 4.9 MW_p installed in public buildings such as schools, hospitals, clinics and offices. This was followed by a PV Field Test for industrial use, which had achieved 4.7 MW_p of PV on warehouses, factories and commercial buildings by the end of 1999. Other programmes provide subsidies for local public organisations and private industrialists who are establishing new energy businesses.

The German 100 000 Roofs Solar Power Programme was launched on 1 January 1999 as a market introduction programme. This provides loans at low interest rates (see Table 4.1 for conditions). By the end of 1999, 3 576 applications (equivalent to 9 MW_p) had been accepted, although this was only half of the anticipated installed capacity. The Renewable Energy Law (which was passed in April 2000) should accelerate the PV market dramatically.

In the USA, a 10 year plan to deploy one million 'solar' roofs was issued early in 1998 (this covers both solar thermal and PV systems). Although the tax credit has not yet been approved by Congress, the initiative has moved forward in 1999 with the formation of state and local partnerships, financing for PV systems, net metering in 30 states and PV for federal buildings. Other programmes include the Sacramento Municipal District (SMUD) Pioneer programme, which equipped 400 homes with utility-owned and maintained PV systems. Pioneer II was initiated in 1998 with the objective of installing 5 MW_p by the year 2005. The aim of the programme is to evaluate the performance of the components and system and to test the impact of 10 years of bulk purchasing on the installed cost. In California the Emerging Renewables Buydown Programme, led to 2.2 MW_p of PV being installed in 1999 on both commercial and residential buildings.

Apart from national or regional demonstration programmes there are a number of high profile, building-integrated PV projects worldwide. PV features prominently in the Sydney 2000 Olympics with a 70 kW_p array on the Superdome, innovative PV streetlights and 629 kW_p installed on houses in the Newington (athletes') village. In 1999, the Nieuwland project in Amersfoort (the Netherlands) was completed. A total of 1.3 MW_p has been installed on the new housing development, providing a role model for future urban expansion. Projects such as the Newington village and Nieuwland are also being used to investigate network issues involved with such a high density of small, embedded generators. In Germany, the world's largest building-integrated PV array began operation in 1999 at the Academy Mont-Cenis Herne: a 1 MW_p PV system was integrated into the enormous glass envelope (with a roof area of 12 000 m^2) to provide shading, daylighting and electricity production. This was one of 20 PV plants selected as 'Expo 2000' projects at the world exhibition in Hannover. In connection with the movement of the German Government and Parliament from Bonn to Berlin, 14 PV plants with a total installed power of 760 kW_p have been included in the new building work. These have been installed in prominent positions such as the German Parliament, Chancellor's building and Ministry of Economy and Technology. BP Amoco are also installing PV on petrol stations: 400 kW_p were installed in the UK in 1999 as part of the global 'Sunflower' project, providing a very visible signal of the future shift from a fossil fuel to a renewable based society.

Increasingly evident is the emphasis on education in PV demonstration projects. For example, the new Earth Centre in the UK, the Kortright Centre for Conservation and the British Columbia Institute of Technology in Canada and the 'Nordic Ark' in Sweden all incorporate PV as a key feature in the design. Many countries are also installing PV systems on schools: for example the UK 'Scolar' programme (20 systems installed by the end of 1999), the 'Sun at School' programme in Germany (total installed power about 2 MW_p) and the Eco-School Infrastructure Promotion Project in Japan (systems installed on 23 schools and 85 universities by the end of 1999). In Israel five educational solar 'villages' have been established where PV generated electricity is used to operate games, kits and fountains. 50 similar kits have been supplied to additional schools. By targeting a younger audience the aim of such projects is to build a base of awareness that will permit widespread application of the technology in the future. The Internet has also been used, in some cases, as a tool to exchange performance data.

2.4 Budgets for market stimulation, demonstration and R&D

The trend in the total government budget allocated for PV in the reporting countries is shown in Figure 2.3. The total budget increased by 4 % between 1998 and 1999 to 479 MUSD[4]. Although the budget for R&D has varied there is no clear trend and it remains similar to that allocated in 1994. The budget for demonstration has doubled since 1994 but still only accounts for a small percentage of the total. The increase in the total budget, therefore, is due to the steady rise in the money spent on initiatives to encourage the market deployment of PV, which is reflected in the growth in installed capacity (Figure 2.1).

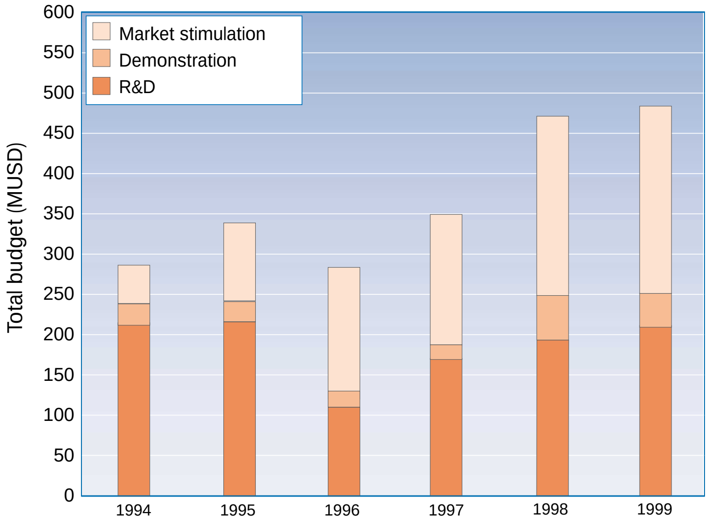


Figure 2.3 - Breakdown for market stimulation, demonstration and R&D between 1994 and 1999

The 1999 budget for each of the reporting countries is shown in Table 2.3. The vast budget for PV in Japan accounts for over half of the total budget for the reporting countries. Although relatively small in absolute terms, a number of the countries saw significant increases in the PV budget in 1999: in particular France, which increased its budget by 70 %, the Netherlands, the UK and Australia.

Table 2.3 - Budget for R&D, demonstration and market stimulation in 1999 in MUSD

	AUS	AUT	CAN	CHE	DNK	DEU	FIN	FRA	GBR	ISR	ITA	JPN	KOR	MEX	NLD	NOR	SWE	USA
R & D	1.68	1.92	0.46	8.33	0.46	26.86	0.76	7.60	3.84	0.19	5.00	90.65	1.16	0.59	29.13	0.46	2.47	35.0
Demo	2.34	0.00	0.13	2.13	0.86	0.62	0.01	0.00	0.00	0.00	0.50	23.55	0.38	0.00	11.02	0.00	0.00	0.00
Market stimulation	0.90	0.00	0.29	3.53	0.00	18.71	0.00	8.70	0.00	0.00	0.00	149.91	0.00	0.00	7.09	0.00	0.00	31.50
Totals	4.92	1.92	0.89	14.00	1.32	46.19	0.77	16.30	3.84	0.19	5.50	264.11	1.55	0.59	47.24	0.46	2.47	66.50

Chapter 3 Industry and growth

3.1 Photovoltaic cell and module production

168 MW_p of modules were manufactured in the reporting countries in 1999. The trend in module production is shown in Figure 3.1 and production is separated according to world region in Table 3.1.

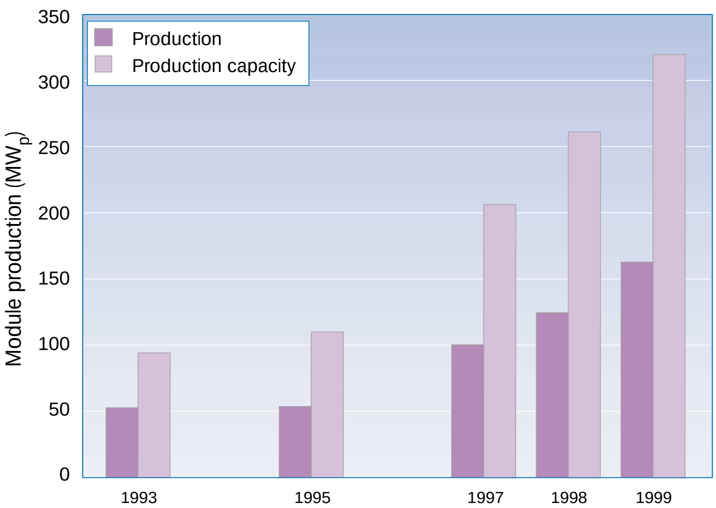


Figure 3.1 - PV module production and module production capacity between 1993 and 1999

Total module production increased by 34 % between 1998 and 1999[5]. This growth took place primarily in Japan and the USA[6]. In Japan module production increased by 67 % between 1998 and 1999, with three companies (Kyocera, Sharp and Sanyo Electric) producing over 10 MW_p each. Over half of all the modules produced in the reporting countries in 1999 (51 %) were from Japan and this trend looks set to continue with capacity planned to exceed 200 MW_p in 2000. The USA accounts for 35 % of all cells manufactured in the reporting countries but only 26 % of the modules since it exports a large fraction of the cells. In Australia, module production was temporarily affected by the merger of BP and Amoco.

Figure 3.1 shows that utilisation of production capacity remains low (52 %). In some countries, such as Korea, there is surplus capacity according to market demand. However, the low utilisation largely reflects the rapid expansion of the industry with large plants being built, but not yet fully operational.

Module production remains based, predominantly, on crystalline silicon technologies (84 %), of which approximately

[4] The 1999 budget does not include data for Spain and Portugal. Since the Spanish budget is considerable, the total budget has actually increased by more than 4 % since 1998.

[5] Module production in the USA in 1998 has been revised since the previous International Survey Report, from 53.9 MW_p down to 36.8 MW_p. The total module production in 1998 has been adjusted accordingly to 125.6 MW_p.

[6] In order to avoid 'double counting', modules are considered to be manufactured in a country only if the encapsulation takes place in that country.

Table 3.1 - PV cell and module production in 1999 by region

Region	Cell production (MW_p)	Module production (MW_p)				Module production capacity (MW_p)
		Crystalline	Amorphous	Other	Total	
USA	60.80	34.40	5.00	4.20	43.60	94.10
Japan	79.62	69.97	15.01	0.00	84.98	145.20
Europe	23.94	29.32	2.40	0.00	31.72	73.33
Rest	7.00	7.50	0.00	0.00	7.50	12.50
Totals	171.36	141.19	22.41	4.20	167.80	325.13

60 % is multicrystalline and 40 % is single crystalline. However, amorphous silicon production more than doubled between 1998 and 1999. Traditionally used only for consumer products (< 40 W_p), amorphous silicon is now emerging as a viable alternative in the PV power market. Kaneka's 20 MW_p a-Si plant began production in Japan in 1999 and Sanyo Electric have commercialised an a-Si /sc-Si bifacial module with a record efficiency of 20.1 %. 'Other' technologies that are beginning to be commercially produced are cadmium telluride (CdTe) and copper indium diselenide (CIS). Regarding CdTe: Antec Solar announced a 10 MW_p plant (due to be completed by 2001) in Germany and First Solar should complete the first stage of a 100 MW_p cell and module production line in the USA in 2000. Regarding CIS: Würth Solar plan to start pilot production in Germany in 2000 and modules are being produced on a pilot basis in the USA by Siemens Solar. AstroPower produced over 1 MW_p of their new silicon film in 1999 and several companies in Australia are also developing thin film products.

Table 3.2 lists the module manufacturers in each of the reporting countries. The manufacturers can be divided into two broad categories: firstly, those who purchase ready made cells and assemble them into modules; secondly, vertically integrated manufacturers who manufacture their own cells and modules. Amorphous silicon manufacturers are always vertically integrated because the cell and module are built in the same process.

In Germany module production increased from 6.4 MW_p in 1998 to 8.8 MW_p in 1999. Targets for the 100 000 Roofs Solar Power Programme led to the foundation of new companies and realisation of planned production capacity extensions. It is planned to extend the 27 MW_p capacity to 34 MW_p by the end of 2000 and 70 MW_p in 2001. A number of new companies in Australia and the USA are either in pilot production or planning to enter production. There is currently no manufacturing capacity in Austria, Finland, Israel, Mexico or Norway; although one Israeli company is due to begin production in 2000 and there are plans to start production of cells in Norway.

A number of countries that have little, or no, module manufacturing capacity, are active in other areas. For example, Isovolta/Werndorf (Austria) produce and export approximately 50 % of the world demand for tedlar for PV modules. Crystalox (UK) and ScanWafer (Norway) are major exporters of multicrystalline silicon ingots and wafers and Automated Tooling Systems (Canada) have developed and marketed automated photovoltaic cell and custom manufacturing module lines.

3.2 Balance of system component manufacturers and suppliers

A large industry exists manufacturing balance of system components such as inverters, batteries and battery charge controllers, d.c. switchgear and array support structures. The *PV Technology Note* provides a brief technical description of these components.

The price of grid-connect inverters remains similar to 1998: typically between 0.8 - 1.0 USD/VA for inverters in the range of 1 - 10 kVA, although prices below 0.7 USD/VA are reported in the USA and Germany. Prices are generally lower for larger inverters and can be as low as 0.35 USD/VA for inverters above 100 kVA. Stand-alone inverters also tend to be cheaper since they do not need the additional control and protection functions required for grid-connection and are not, generally, required to produce a pure sine wave output.

In the absence of an international standard for grid-connection, the choice of inverters is largely determined by those manufacturers that comply with the requirements for connection pertinent to a particular country. Manufacturers in the USA and the Netherlands are now offering small inverters (~100 VA) for a.c. modules and one manufacturer is currently developing a micro-inverter designed to be plugged directly into a standard wall socket. Many inverters now include a digital output display and data acquisition system connection as standard. Manufacturers in the USA and Germany have developed dual inverters (with a few days storage) so that grid-connect systems can also be used as a back up for the grid. Fears concerning Year 2000 compliance (the 'millennium bug') created a new image for PV as a residential UPS (uninterruptible power supply).

Over 100 000 charge controllers were sold by US suppliers alone in 1999 (80 % exported). Manufacturers in France and Germany offer charge regulators with prepayment function and integrated battery, providing a portable, easy-to-use system. In France computer software has been developed to enable data analysis and remote control of off-grid PV systems through satellite or telephone networks.

3.3 System prices

For off-grid systems, prices vary widely depending on the application and the climate in which it is installed. For example, in the US sunbelt, d.c. systems can be installed with 4 to 5 days storage. In such a 'bare bones' system with PV arrays purchased from a distributor, mounting hardware, charge controller and lead-acid deep-cycle battery bank, a local installer can profitably install the system for 12 - 14 USD/W_p (d.c.). In a moderate climate an a.c. system with

PV technology note

The key components of a photovoltaic system are the **photovoltaic cells** (interconnected and encapsulated to form a **module**), the **inverter**, the **battery** and **charge controller** (for off-grid systems) and the **mounting structure**.

Cells

At present the vast majority of photovoltaic cells are made from silicon. In general, cells are classified as either crystalline (sliced from ingots or castings or grown ribbons) or thin film (deposited in thin layers on a low cost backing).

Crystalline silicon

Single crystal silicon cells are usually manufactured from a single crystal ingot, most commonly grown by the Czochralski method. PV cells made from multicrystalline silicon have now become popular as they are less expensive to produce, although slightly less efficient. Multicrystalline cell manufacture usually begins with a casting process in which molten silicon is poured in a rectangular block. This produces a block of multicrystalline silicon that is then sliced into wafers that are used to make the cells. One way of eliminating the sawing step is to grow ribbons of multicrystalline silicon that are already wafer thin and the correct width for use as PV cells.

The maximum recorded cell efficiency for crystalline silicon is 24.7 %[7]. Cell efficiencies greater than 25 % have been recorded for cells made from III-V semiconductor material (for example gallium arsenide (GaAs)). However, these materials are reserved for concentrator systems and for space applications because of their high cost.

Thin film

Thin film modules are constructed by depositing extremely thin layers of photovoltaic materials on a low cost backing such as glass, stainless steel or plastic. Individual 'cells' are formed by then scribing through the layers with a laser. Thin film cells offer the potential for cost reductions. Firstly, material costs are lower because much less semiconductor material is required and, secondly, labour costs are reduced because the films are produced as large, complete modules and not as individual cells that have to be mounted in frames and wired together.

The most fully developed thin film technology is hydrogenated amorphous silicon. This is the material normally used in consumer applications, although it is used, but less frequently, in power modules. The efficiency of commercial amorphous silicon modules has improved from around 3.5 % in the early 1980s to over 7 % currently. The most efficient modules are made with multiple layers of photovoltaic material, for instance three layer amorphous silicon modules with germanium added to two of the layers (a-Si/a-SiGe/a-SiGe) which have a record cell efficiency of 13.5 %[7]. Other types of thin films can be made using polycrystalline silicon, cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS).

Typical and maximum module and cell conversion efficiencies (at Standard Test Conditions, i.e., 1 000 Wm^{-2}, 25 ºC, solar spectrum AM 1.5) are given in the table below for some of the commercially available PV technologies.

Type	Typical module efficiency (%)	Maximum recorded module efficiency[7] (%)	Maximum recorded laboratory cell efficiency[7] (%)
Single crystalline silicon	12-15	22.7	24.7
Multicrystalline silicon	11-14	15.3	19.8
Amorphous silicon	5-7	-	12.7[9]
Cadmium telluride	-	10.5	16.0
CIGS	-	12.1[8]	18.2

[7] *Solar Cell Efficiency Tables, Version 15, M.A.Green, K. Emery, D.L. King, S. Igari, Progress in Photovoltaics: Research and Applications, 8, 187-195 (2000)*
[8] *Alloy with sulphur*
[9] *Unstabilised results*

Module

For crystalline silicon cells, after testing and sorting to match the current and voltage, the cells are interconnected and encapsulated between a transparent front, usually glass, and a backing material. This 'module' is then typically mounted in an aluminium frame. Modules are normally rated between 50 and 200 W_p, although several manufacturers now offer modules above 200 W_p.

Inverter

An inverter is used to convert the d.c. source (from the module or battery) to a.c. The efficiency of inverters is generally greater than 90 %, when the inverter is operating above 10 % of its rated output, and can peak as high as 96 %. Inverters connected directly to the module (as opposed to through a battery) incorporate a Maximum Power Point Tracker (MPPT), which continuously adjusts the load impedance such that the generator is always extracting the maximum power from the system.

Inverters fall into two-main categories: self-commutated and line-synchronised. The first can operate independently, being activated solely by the input power source; the line-synchronised inverters are triggered directly from the grid. Utilities require that inverters connected to the grid must contain suitable control and protection to ensure that systems are installed safely and do not adversely affect the power quality.

Traditionally, one inverter was used for the whole array. Now separate inverters may be used to connect each 'string' of modules or even mounted on the back of individual modules ('a.c. modules'). String inverters and a.c modules are likely to be increasingly used in the building-integrated PV market because they permit easy system expansion, independent operation and easier installation.

Battery

For off-grid systems a battery is used to provide energy storage. Nearly all batteries used for PV systems are of the lead-acid type (with a small quantity of antimony to reduce self-discharge). Nickel-cadmium batteries are also suitable and have the advantage that they cannot be overcharged or discharged, but are considerably more expensive.

All PV batteries are deep-cycle i.e. designed to be discharged down to 50 % or more without damage so that they can supply power over a long period of time (in contrast to a car battery, for example, which is usually only discharged down to 3 to 5 %). The lifetime of a battery varies depending on factors such as how it is used, how it is maintained and charged, and temperature, but is typically 5 -10 years.

Charge controller

The primary function of a charge controller (or regulator) is to maintain the battery at the highest possible State Of Charge (SOC) and provide the user with the required quantity of electricity, while protecting the battery from deep discharge (by the loads) or extended overcharge (by the PV array). Most charge controllers operate via voltage regulation set points. However, as voltage is not representative of the true SOC, new algorithms are being developed to evaluate the state of the battery, based on Ah or combined VAh monitoring.

Additional features such as battery temperature or wire compensation, meters and alarms can enhance the ability of the charge controller to meet the load demand and extend battery lifetime. Other functions such as MPPT, d.c/d.c. conversion, anti-theft protection, load management, pre-payment and data logging can also now be built into the charge controller.

Mounting structure

With the rapid growth of on-grid distributed systems, a wide range of products have been developed for installing PV modules on buildings. These include mounting structures for PV facades, roof profiles, flat roofs and even 'PV tiles' that can be used to replace conventional roof tiles. New products are addressing the need for ease of integration into the building envelope and aesthetic appeal.

Table 3.2: Module manufacturers in the reporting countries

Country	Company	Cell Production (MW$_p$)	Module Production (MW$_p$)	Production Capacity (MW$_p$)	Module Type	Additional Information
AUS	BP Solar Australia	5.0	5.0	6.0	sc-Si	Merger will see new joint cell production in Sydney. Module production will remain at Solarex plant in Sydney - module production expected to reach 20 MW$_p$ by 2001.
	Solarex	2.0	2.0	5.0	mc-Si	
CAN	Canrom Photovoltaic[1]				sc-Si	Now manufactures own cells; produces a standard line of 12, 30, 40 and 50 W$_p$ modules.
CHE	Star Unity	0.0	0.02	0.1	sc-Si	Import cells and integrate them into roof tiles ('Sunny Tile')
	Atlantis Solar Systems	0.0	0.4	1.2	sc-Si	Produce custom laminates using imported cells and 'Sunny Tile' roofing shingles. Also have production facilities in Germany and USA of 1 MW$_p$ capacity.
DNK	Gaia Solar	0.0	0.075	0.33	mc-Si, sc-Si	Produce modules (27 - 150 W$_p$) from imported cells. Production more than doubled in 1999.
DEU	>20 companies[1]	4.1	8.8	27.0	mc-Si, sc-Si EFG, a-Si	See text
ESP	Atersa	0.0	1.0	1.5	sc-Si	No change in production.
	BP Solar España	4.4	4.6	10.0	sc-Si	
	Isofoton	0.643	3.37	5.0	sc-Si	
FRA	Photowatt International	8.5	3.0	10.0	mc-Si	Manufacturing PV cells and modules since 1978. Installed a new automated cell manufacturing line in 1999. Innovation: 'POLIX' directional solidification ingot casting and wire-sawing of thin wafers.
	Free Energy Europe	0.4	0.4	1.0	a-Si	The Dutch company purchased the a-Si plant from Naps-France in May 1998. Produce modules of 12 W$_p$ for small power applications (up to 100 W$_p$).
GBR	Intersolar	1.5	1.5	2.5	a-Si	Production capacity has increased from 1.6 MW$_p$ per annum (1998). Further increase to 3 MW$_p$ planned for 2000.
ITA	Eurosolare	0.4 1.1	0.4 1.1	2.5	sc-Si mc-Si	sc-Si wafers are bought on the international market; mc-Si wafers are home made. Production of mc-Si modules has decreased from 1.8 MW$_p$ in 1998.
	Helios Technology	2.1	2.05	2.2	sc-Si	Fabricate single crystal silicon cells and modules, and design and supply turnkey PV systems.
JPN	Kyocera	30.2	30.2	36	mc-Si	Module production has increased from 24.5 MW$_p$ (1998). Production capacity increase to 60 MW$_p$ planned for 2000. Have commercialised solar cell roofing material 'ECONOROOF'.
	Sharp	8.5 21.3 0.2	8.5 21.3 0.2	10.0 22.0 2.2	sc-Si mc-Si a-Si	Production of modules has increased dramatically, from 14.0 MW$_p$ (1998). Plan to double capacity of mc-Si production capacity to 44 MW$_p$ in 2000. New developments: mc-Si cell with efficiency of 16.0 %.
	Sanyo Electric	4.6 5.9	4.6 5.9	5.0 8.0	a-Si a-Si/sc-Si	In 1998 module production was only 3.5 MW$_p$. Has commercialised a-Si/sc-Si bifacial module and plan to increase production capacity from 8 to 11 MW$_p$ in 2000.
	Canon	1.31	1.31	10.0	a-Si	Module production decreased from 2 MW$_p$ (1998)

Country	Company	Cell Production (MW_p)	Module Production (MW_p)	Production Capacity (MW_p)	Module Type	Additional Information
	Showa Shell Sekiyo	0.0	1.5	5.0	sc-Si	Production capacity has increased but actual production decreased (compared to 1998). Have developed combination of triangle module and square module for residential buildings.
	Air Water (former Daido Hoxan)	0.1 0.01	0.94 0.03	1.0 1.0	sc-Si mc-Si	No change in production.
	Mitsubishi Electric	4.5	4.5	10	mc-Si	Began production in 1999. Plan to increase production capacity to 15 MW_p in 2000.
	Kaneka	3.0	3.0	20.0	a-Si	Largest a-Si manufacturing plant in the world, began production in 1998.
	MSK	0.0 0.0 0.0	3.0 0.0 0.0	10.0 3.0 2.0	mc-Si sc-Si a-Si	Commisssioned sc-Si and a-Si plant and increased capacity of mc-Si plant from 3 MW_p. Plan to increase total production capacity to 28 MW_p in 2000.
KOR	LG Industrial Systems	0.0	0.2	1.0	sc-Si	Unlikely to increase production capacity since local market size is significantly less than current capacity.
	Samsung Electronics	0.0	0.3	0.5	mc-Si	
NLD	Shell Solar Energy	0.8	4.0	6.0	mc-Si	No change in production in the Netherlands. The standard 95 W_p product can be delivered as an 'AC module' containing a mini-inverter that has been approved for installation in the Netherlands.
SWE	GPV	0.0 0.0	0.5 0.5	2.0 2.0	mc-Si sc-Si	Until 1998, produced only sc-Si modules; production of mc-Si modules decreased by 1 MW_p in 1999. Plan to enlarge capacity up to 10 MW_p during 2000.
USA	Siemens Solar Industries	22.2 0.0	17.0 0.0	25.0 4.0	sc-Si CIS	Pilot production of CIS product began in 1998; large-area modules with efficiencies > 12 % have been produced.
	BP Solarex	16.0 2.0	12.0 2.0	20.0 5	mc-Si a-Si	Offers modules from 33-200 W_p. Production of mc-Si modules increased from 10 MW_p in 1998 to 12 MW_p and 2 MW_p of a-Si modules were shipped in1999.
	AstroPower	11.0 1.0	4.0 0.0	20.0 5.0	sc-Si Si film	sc-Si cell and module production increased dramatically from 6.1 MW_p and 2 MW_p respectively in 1998. 1 MW_p of the new thin film on low-cost substrate product was produced in 1999; full production (of the 9 MW_p plant) is expected in 2000.
	Solec International	0.6	0.6	0.6	sc-Si	sc-Si cell and module production almost terminated in 1999 in order to produce 5 MW_p of n-type slices for their owners Sanyo.
	ASE Americas	4.0	4.0	5.0	EFG-Si	Completed a major expansion of their plant in 1998. Produce large (200-300 MW_p) as standard.
	United Solar Systems Corp (USSC)	3.0	3.0	4.5	a-Si	Production of 5 MW_p triple-junction a-Si plant began in 1997. In addition to standard power modules, produce two building-integrated products.
	Other	1.0	1.0	5.0		Other companies nearing production: Evergreen Solar, Ebara Solar, First Solar, Energy Photovoltaics, plus companies specialising in concentrator cells.
Totals		171.36	167.80	325.13		

[1] *Data not available for publishing. Note: for a-Si, the cell and module are manufactured in the same process.*

Key: sc-Si = single crystal silicon. mc-Si = multicrystalline silicon. EFG = edge fed growth silicon. a-Si = amorphous silicon.

CIS = copper indium diselenide. CdTe = cadmium telluride.

10 days storage, a stand-alone inverter and ground-mounted hardware, can be installed for 14 - 18 USD/W_p. High reliability systems in moderate climates with 20 days of storage, all weather mounts, battery enclosures, system controllers etc. can cost at least 24 USD/W_p. A similar range is seen in the other reporting countries, although systems in the Netherlands, Australia and France can be up to 30 USD/W_p. Prices have not altered significantly since 1998.

On-grid systems are generally cheaper because no batteries and associated components are necessary. For on-grid, building integrated systems of 1 - 3 kW_p, system prices[10] are below 6 USD/W_p in Denmark and Germany and below 7 USD/W_p in Australia and France. In the USA, systems installed by Sacramento Municipal Utilities District (SMUD) range between 5 - 6 USD/W_p but according to SMUD suppliers, the module suppliers and system installers made little or no profit. Systems offered, with profit, outside the SMUD programme sell for 8 - 12 USD/W_p. Between 1998 and 1999, the price of on-grid systems below 10 kW_p decreased in France (by 16 %), Italy (by 6 %) and Japan (by 5 %). System prices actually increased in Finland and Switzerland although, for systems over 10 kW_p, system prices in Switzerland decreased by 5 %. This is because 'solar stock exchange' schemes have led to a market for larger systems. In general, the price of systems above 10 kW_p is substantially lower in many countries and can be as low as 4.8 USD/W_p in Australia.

Chapter 4 Framework for deployment

Deployment of PV systems is governed by local, national and international policies and the perception of the general public and utilities; it is also influenced by the availability of suitable standards and codes.

4.1 New initiatives in photovoltaic power systems

As Figure 2.3 showed, increasing emphasis is being placed on market deployment initiatives as opposed to R&D or demonstration programmes. The key initiatives in each of the reporting countries are summarised in Table 4.1.

A wide range of fiscal instruments are being used to support or promote PV (and other renewables) including: reduced interest rates, tax credits, accelerated depreciation, government or regional grants, preferential tariffs and 'green electricity' schemes. The prevalence of green electricity schemes in the reporting countries demonstrates that a significant, and growing, number of customers are concerned about the environment and prepared to pay more for electricity generated from environmentally-benign sources. Public opinion appears to be generally supportive of PV, although lack of awareness and access to information is a barrier in some countries. Utilities are also increasingly supportive of PV: many offer 'net metering' and some are investing in PV (either to give the company a 'green' image, as in Germany, or to avoid the costs of grid extension in rural areas, as in France and Mexico). The value of other network benefits attributed to PV does not, though, appear to be recognised.

4.2 Indirect policy issues and their effect on the PV market

There are two key issues with an indirect, but important, influence on the PV market: namely, the Kyoto Protocol and deregulation of the electricity industry.

As a consequence of the international Framework Convention on Climate Change and the Kyoto Protocol, countries such as Finland, Germany, Sweden and the UK have introduced, or are planning to introduce, taxes on forms of electricity generation that contribute to CO_2 emissions. These taxes are too small to noticeably affect the economics of PV and in the USA some analysts calculated that PV credits would be less than 0.01 USD/kWh if there were serious efforts to credit PV for mitigation of CO_2. However, in the UK, the money raised from the carbon tax will be used as an additional source of funds for the national renewable energy programme. Perhaps more significantly, the Kyoto Protocol has stimulated a reappraisal of renewable energy policy and the setting of national targets for PV deployment. For example, in Japan a law concerning 'Promotion Measures to Arrest Global Warming' was passed and in Australia a range of new renewable energy programmes, including mandated purchase of renewable energy by electricity retailers, have been introduced as part of the national Greenhouse Strategy. As shown in Table 4.1, Germany, Finland, France, Italy, Japan, the Netherlands and the USA have all set targets for increasing PV deployment dramatically. In addition the European Commission are currently preparing a Directive on renewable energy support, including targets, which is likely to influence PV deployment in its' member countries to some extent.

Since an increasing proportion of PV systems are grid-connected, restructuring of the electricity industry is an important factor. Deregulation has been achieved, or is currently underway, in Australia, Canada, Denmark, Finland, Germany, the Netherlands, Switzerland, the UK and the USA. The impact on PV is uncertain. The increase in green power schemes and net metering is one outcome, as many utilities are expanding customer services and choice in the face of increased competition. Deregulation has also opened up access to the grid. Accompanied by simplified connection procedures and requirements, this has permitted a dramatic growth in embedded generation (such as PV). However, market-led schemes promote the cheapest option and so do not necessarily lead to more PV installations. For example, in Australia, PV accounts for less than 0.1 % of the total green power produced and the New Electricity Trading Arrangements in the UK replace existing subsidies for renewables with an obligation on suppliers to obtain a percentage of their electricity from renewable sources. (Electricity suppliers will therefore select the cheapest renewable technologies). Also, the primary aim of liberalisation in the electricity supply industry is to drive down costs to the consumer. Thus, as electricity prices fall, the price differential separating PV from conventional electricity generation will increase.

[10] *Note: these prices are turnkey prices that exclude VAT/TVA/sales taxes, operation and maintenance costs but include installation costs.*

Table 4.1: New initiatives in the reporting countries

Country	Promotional Initiatives	Utility and Public Perceptions	Major New Initiatives and Planned Development
AUS	A number of utilities offer net metering for domestic PV systems. Utility Green Power programmes grew rapidly during 1999 with over 58 000 customers nationwide, although to date PV only accounts for 0.1 % of the total Green Power produced. As part of Green Power schemes, one utility offers 0.17 USD/kWh for electricity exported from PV and another utility uses customer donations, via rounding up of electricity bills, for the installation of PV systems on schools.	Public support for PV and other renewables continues. However, grid-connected customers in particular lack access to information on availability, cost and performance of PV systems and have a limited understanding of the potential role of renewables in the electricity supply network.	Several new renewable energy programmes are planned for 2000 and 2001. The Australian Greenhouse Office will provide support for up to 50 % of the cost of domestic building integrated PV systems and up to 50 % of the cost of conversion of diesel-based off-grid electricity generation to renewable energy technologies. The Renewable Energy Industry Development programme and Renewable Energy Equity Fund will also benefit PV.
AUT	Preferential tariffs ranging between 0.32 to 0.80 USD/kWh. Some regional governments subsidise PV; in Upper Austria subsidies up to 50 % of the total installed cost are available.	Most utility companies have installed PV systems for demonstration purposes or to supply isolated areas. In Upper Austria 23 % of the customers who contributed to the green electricity programmes decided to subsidise PV.	Decisions concerning funding of renewables have been delayed until the effect of the new electricity trading rules is evident.
CAN	Accelerated depreciation for the cost of PV systems greater than 3 kW_p resulting in Sales Tax reduction and, in Ontario, two utilities accept net metering for PV. 1999 saw a marked increase in on-grid PV systems as a result of the Greenpeace Solar Pioneers programme.	PV is attractive to the public for vacation cottages/cabins and recreational vehicles but the general perception is still that PV is too expensive. It is expected that deregulation of the electricity market will allow an increasing number of customers to support solar energy for environmental reasons and green electricity options are being implemented in some regions.	The Government, in collaboration with the Canadian Solar Industries Association, is planning a marketing and promotional initiative to raise awareness of PV.
CHE	The 'solar stock exchange' plays a major role in providing a market for building integrated PV systems. The utilities act as a 'stock exchange' for trading between independent PV generators and customers who are willing to pay a premium for solar energy.	The Government's 'Energy 2000' programme and the Swiss Utilities Association are working to ensure that all customers have access to the 'solar stock exchange'. In 1999, 1.2 % of the 1.8 million households able to purchase 'green electricity' did so.	In September 2000 there will be a public referendum on the introduction of a levy on non-renewable energy and a longer-term ecological tax reform. In the city of Basle new legislation has been introduced which will help fund 300 kW_p of additional PV power per year over a six year period, resulting in an average of 8.5 W_p per resident in the city.
DNK	Subsidy of up to 36 % for PV applications in the commercial sector, funded by the CO_2 tax on electricity (little use has been made of this so far). Net metering for privately owned PV systems was established in mid 1998 for a trial period of 4 years.	Polls reveal a high consumer interest in PV and a willingness to pay more for 'green electricity'. A new law deregulating the electricity sector is likely to influence PV deployment.	A 300 roof top project was launched in 1998; about half of the systems had been installed by the end of 1999. In late 1999 the Danish Parliament allocated 3.9 MUSD for a 3 year programme to promote the use of PV on buildings and to foster the development of appropriate building-integrated PV products.
DEU	The 100 000 Roofs Solar Power Programme, launched on 1 January 1999, provides loans with low interest rates (0 % in 1999) for 10 years. The loan is to be repaid in 8 installments (12.5 %) from years 3 to 10, whereas the last installment is not due for repayment if the PV plant is still in operation. In addition to the Government subsidies, 10 of the 16 Federal states are supporting PV installations, particularly Nordrhein-Westfalen.	Public opinion concerning renewable energy remains very positive. By the end of 1999 more than 50 suppliers were offering green power, compared to 11 suppliers by the end of 1998, and the number continues to increase. Utilities are participating in the green power market and this has resulted in a growing number of 'green-power' plants - a combination of different renewable energy plants, including PV.	The initial response to the 100 000 Roofs Solar Power Programme was disappointing with applications for 9 MW_p instead of the expected 18 MW_p. However, the Law for the Priority of Renewable Energies, which will come into force in 2000 should accelerate the market dramatically. The Law replaces the Renewable Energies Feed-in Tariff Law of 1991 and sets a buy back rate of 0.51 USD/kWh for PV generated electricity. The target capacity for the Programme is 300 MW_p by 2003.
ESP	Regional programmes to support PV provide subsidies of over 25 % of the installation cost. Electricity generated from PV receives a preferential tariff of 0.4 USD/kWh (for systems less than 5 kW) and 0.2 USD/kWh (for systems greater than 5 kW).	Public perception of PV is positive, particularly due to the low visual impact. Several Spanish utilities have invested substantially in grid-connected PV systems.	The Energy Saving and Efficiency Programme (PAEE) ended in 1999, but grants to PV will continue under the new programme for renewable energy (2000-2006), which is currently awaiting approval.
FIN	Investment subsidies of up to 30 % are available for companies installing PV systems. Preliminary interest has been shown in an ESCO type financing approach for PV installations on private homes.	'Green electricity' schemes have been introduced and utilities are increasingly interested in demonstrating building integrated PV systems as part of their environmentally friendly image.	The Ministry of Trade and Industry launched an Action Plan for Renewable Energy Sources in 1999. This set a target of 40 MW_p of installed capacity by 2010 which represents an increase in PV electricity production by 40 fold compared with the base year 1995.
FRA	Up to 95 % of the cost of an off-grid domestic PV system is subsidised (70 % from the Fonds d'Amortissement des Charges d'Electrification (FACE) fund, 15 % from the Finance Ministry and 10 % from ADEME). Between 35-80 % of the cost of on-grid systems can be funded through the PHEBUS initiative, a demonstration programme of the EC (ends in 2000).	EDF (the main electricity utility) and ADEME continue to promote the use of PV (and wind) for isolated houses, where grid extension is a more expensive option, through the FACE programme.	A new demonstration programme for on-grid building integrated systems was initiated in 1999 partly funded by the EC. The aim is to install 500 kW_p in the next 3 years with a targeted installation cost of 5 USD/W_p. Due to a Government decision (in 1998) to reinforce the public budget for the development and promotion of renewables, ADEME has tripled its budget for PV dissemination and aims to install 1 500 kW_p of off-grid systems per year.

Country	Promotional Initiatives	Utility and Public Perceptions	Major New Initiatives and Planned Development
GBR	Government funding is restricted to R&D. Marketing of PV is left to organisations such as Solar Century.	The utility perception of PV is improving but in general utilities are more concerned with the connection of other small embedded generators such as micro-CHP Stirling engines which are viewed as more likely to take-off in the UK. The PV industry continues to lobby for net metering and policy changes.	The large increase in installed capacity in 1999 is largely due to the ongoing BP Amoco 'Sunflower' project. A number of large building integrated PV projects are planned for 2000 when the Government's 100 roofs domestic field trial will also begin. VAT on PV systems will be reduced from 17.5 % to 5 % with effect from April 2000 and the Climate Change Levy will be used to support renewables in general.
ISR	The Government provides support for PV grid-connected demonstration projects but the support is conditional on bringing the proposed project to a state of being 'cost effective'. To date no one has taken advantage of this offer.	Public perception of PV is increasingly positive as a result of greater awareness of environmental issues in general. However, the industry is hampered by continuing thefts of modules and systems increasing installation costs (extra shielding) and maintenance (guard duty) for some isolated applications.	Three major new projects are being developed. In Yeruham, a number of solar projects to provide social and educational benefits. In Nitzana, building a Solar Demonstration Park and establishing a new solar energy curriculum for pupils. In Kibbutz Samar, plans to expand an existing PV power station from 4.5 kW_p to 200 kW_p capacity.
ITA	Tax reductions of 36 % of the investment cost of a PV system are available and a VAT reduction from 20 % to 10 %. Electricity generated from PV receives a preferential tariff of 0.18 USD/kWh for plant commissioned within the year 2000.	The utilities have demonstrated their support for the national roof-top programme by co-operating with ENEA to address technical issues relating to grid connection and some utilities are starting their own demonstration programmes. There is also widespread interest from the general public.	The 10 000 roof top programme has been delayed further but is expected to start in 2000. The target capacity is 50 MW_p.
JPN	The taxable amount of fixed property is reduced to 5/6 for 3 years if PV is installed. Owners can also choose either a tax credit of 7 % of the acquisition value of the PV system or 30 % depreciation for the first year. Some financing institutions offer preferential loans to homebuyers for PV systems. Net metering has been available since 1992.	Several utilities have established a subsidy to support R&D on PV systems and a subsidy of half the cost of residential PV installations. Public support for PV is growing and this is evident in a doubling in the number of applications for the Residential PV System Dissemination Programme in 1999.	The existing demonstration and field test programmes expanded dramatically in 1999, making steady progress towards a target of 5 000 MW_p of installed PV capacity by 2010.
KOR	The Government supports demonstration and field tests of various renewable energy sources; PV remains a 'high priority' sector.		
MEX	Government grants are available to isolated and poor communities for rural electrification.	During 1998-99 the national utility sponsored a study to evaluate the effectiveness of the PV Rural Electrification Programme.	A large programme is to be launched in 2000 by the Agricultural and Hydraulic Resources Ministry to support PV applications in agriculture e.g. water pumps for irrigation, cattle watering and electric fencing.
NLD	Apart from government subsidy through the national PV programme, a wide range of support mechanisms are used to finance PV including: low interest rates for 'green projects', accelerated depreciation on environmental investments, a 'green mortgage' for energy efficient and sustainable buildings and green electricity schemes. A generic subsidy for PV is currently being prepared in order to speed up market deployment.	Utilities are active in project development and subsidising of PV. For many companies, like utilities and the building industry, investing in PV is seen as a strategic choice expected to create new business opportunities. According to a market survey conducted by Greenpeace, many customers would be willing to purchase a small PV system and PV is widely regarded as the most promising renewable energy option for the Netherlands in the long run.	The Government has set targets of 250 MW_p of installed PV capacity by the year 2010 and 1500 MW_p (equivalent to about one million roof top systems) by the year 2020. A new PV Covenant (a treaty signed by 28 parties - industry, utilities, R&D sector, government) is being prepared for the period 2001-2007. Key issues are financing and facilitating market development. Participants in the PV Covenant have also discussed the possibility of raising the target for installed power to 500 MW_p by 2007.
NOR		Growing interest from utilities to include PV in future programmes.	Production of multicrystalline silicon wafers due to increase from 6 MW_p to 30 MW_p in next three years; plan to begin production of PV cells.
SWE	There are no general subsidies for PV. However, government funding of up to 50 % can be obtained for a demonstration project.	The general view of PV as a long-term sustainable renewable energy technology is positive.	Until recently the main activity in the national programme has been to identify and develop niche applications where PV will be cost effective as a stand-alone system. In the last couple of years the programme focus has shifted towards evaluating the application of PV in the built environment as a longer-term option.
USA	The key initiatives in the on-grid distributed sector are: the Million Solar Roofs Initiative, the Sacramento Municipal Utility District (SMUD) Pioneer programme, the California PV Subsidy programme and the PV for Schools programme. By the end of 1999, 12 states had enacted restructuring legislation including such options as net metering, green pricing and set-asides for environmentally benign renewables.	Concerns regarding Year 2000 compliance created a new image for grid-connected PV and led to a surge of sales of PV as a back up power system. The Utility Photovoltaic Group (UPVG) supports net metering as a mechanism for expanding PV markets and has installed nearly 6 MW_p of utility-owned or endorsed PV systems.	In 1998 the Department of Energy issued a 10 year plan to stimulate the deployment of one million 'solar' (PV and solar thermal) roofs. The tax credit for the initiative is still awaiting approval from Congress but progress has been made through a series of public meetings and building partnerships with agencies, states and local entities.

4.3 Standards and codes

The International Electrotechnical Commission (IEC) established a Committee (TC 82) in 1981 to prepare international performance and safety standards for PV. The IEC have published 26 International Standards addressing PV cells, modules and stand-alone PV systems.

Currently, IEC standards development is most active in the grid-connect sector and a number of countries have developed, or are developing, guidelines/standards for connecting small PV systems to the electricity network. Both the USA and the UK have recently published guidelines for connecting PV systems to the distribution network. It is interesting to compare the different approach of these two countries. The Institute of Electrical and Electronic Engineers based in the USA has published a Recommended Practice for Utility Interface of PV Systems (IEEE 929) rated 10 kW or less. This standard requires certification from an *independent and accredited laboratory* (using the associated test standard UL1741). The UK guidelines are, in general, less prescriptive and, in line with European industry practices that allows *self-certification by manufacturers* to an approved type test procedure. The approach for the use of a.c. modules is also different. In the USA, a.c. modules can be installed in accordance with the national electrical code if they have been independently certified to the UL1741 standard and meet the requirements of IEEE 929. However, the connection of a.c. modules is not permitted in the UK because of concerns regarding solid-state (as opposed to mechanical) disconnection from the network. This is a major barrier to market expansion and has raised fears that systems may be illegally connected in the UK. With the objective of harmonising the test requirements of PV products internationally, manufacturers and safety test laboratories are currently working together to develop international safety standards for inverters (IEC 62109) and modules (IEC 61730).

Attention is being turned to addressing the d.c. side of the grid connection. Installation guidelines have been published in the Netherlands and are being developed in the UK, Germany, Canada and Australia. The IEC also have a committee (TC 64) which is seeking to extend the existing Wiring Regulations (IEC 60364) to encompass PV installations. Guidelines are urgently required for the electrical contracting industry to address the safety issues unique to PV installations and facilitate training and certification of installers. Co-operation is also required between the building industry and PV industry to include joint development of guidelines and standards.

A major initiative, the Global Approval Programme (PV GAP) was launched in 1997 to promote and maintain quality standards and certification, focusing primarily on stand-alone systems in developing countries and driven by quality concerns of donor programs and the World Bank. PV GAP and IEC technical experts have collaborated on an important project to prepare a new international standard for small PV stand-alone systems.

Chapter 5 Summary of trends

There is great diversity between the countries participating in the IEA Photovoltaic Power Systems Programme and, although this survey does not capture the whole PV market, it provides an indication of global trends. The key trends in PV applications and markets are summarised below and in Table 5.1. Care must be taken in interpreting the statistics due to the very large PV programme in Japan, which is influencing trends in the participating countries to an increasing degree.

- The market for PV power applications continues to expand rapidly: between 1998 and 1999 the total installed capacity in the reporting countries grew by 31 %, reaching 516 MW_p. Of the 121 MW_p installed during 1999, 60 % was installed in Japan alone. Minus Japan, the installed capacity grew by 19 % between 1998 and 1999 (similar to the previous year).

- Off-grid applications account for over 90 % of the total installed capacity in Australia, Canada, Finland, France, Israel, Mexico, Norway, Portugal and Sweden. However, overall, the trend is for an increase in the proportion of PV power that is grid-connected. Between 1992 and 1999, the installed grid-connected PV increased from 29 % to 53 % of the total capacity in the reporting countries. This is due to the large, government-subsidised programmes, especially in Japan and Germany, which focus on PV in the urban environment (on-grid distributed systems).

- Awareness of PV power systems is growing with a number of high profile projects such as the PV installations associated with the Sydney 2000 Olympics, the Amersfoort Nieuwland project in the Netherlands, Expo 2000 projects and new governmental buildings in Germany and PV on petrol stations. Education is increasingly being recognised as a key aspect of national programmes and a number of countries, including Japan, Germany, Israel and the UK have programmes to install PV systems on schools.

- The total budget allocated by government bodies to support the PV industry in the reporting countries has increased from 287 MUSD in 1994 to 479 MUSD in 1999. Over half of the total budget for 1999 was for Japan although other countries, in particular France, saw significant increases in the PV budget. An increasing proportion of the budget is spent on initiatives to encourage the market deployment of PV, as opposed to research, development and demonstration.

- Between 1993 and 1999, module production tripled: from 52 MW_p to 168 MW_p per annum. Japanese production increased by 67 % between 1998 and 1999 and as a result over half of all the modules in the reporting countries were produced in Japan in 1999; largely to feed the increase in demand in the home market. A number of new companies are planning to

Table 5.1 Installed PV power and module production in the reporting countries

Year	Cumulative installed power and percentage increase						Power installed per year	Module production in year
	Off-grid		On-grid		Total			
	MW_p	%	MW_p	%	MW_p	%	MW_p	MW_p
1992	78		32		110			
1993	94	21	42	32	136	24	26	52
1994	112	19	51	24	164	20	28	
1995	132	18	66	29	198	21	35	56
1996	157	19	88	33	245	24	47	
1997	187	19	127	44	314	28	69	100
1998	216	15	180	42	395	26	82	126
1999	244	13	273	52	516	31	121	168

enter production in 2000 in Australia, the USA, Norway and Israel and many companies are planning to enlarge existing production lines. Overall, production remains well below capacity (52 %): this reflects the rapid expansion of the industry with large plants being built but not, yet, fully operational.

- The vast majority of modules produced (84 %) are still crystalline silicon, of which approximately 60 % are multicrystalline and 40 % are single crystalline (a similar split to 1998). However, amorphous silicon production more than doubled between 1998 and 1999 and is now emerging as a viable alternative in the PV power market. CdTe and CIS manufacturing plants are either planned or operational in Japan, Germany and the USA. These will provide a market test for new, lower manufacturing cost, module options. The first stage of a giant 100 MW CdTe cell and module production line should be completed in 2000.

- In general the price of systems has not altered significantly since 1998, although cost reductions were seen in France, Italy and Japan. On-grid building integrated systems of 1 - 3 kW_p are typically between 6 - 12 USD/W_p (installed) although prices below 6 USD/W_p were reported in Denmark and Germany. The new on-grid demonstration programme in France aims to achieve an installed cost of 5 USD/W_p within 3 years. Off-grid systems remain competitive in many applications such as remote houses, telecommunications, water pumping and traffic signals.

- Utilities are increasingly supportive of PV: many now offer net metering or preferential tariffs for PV and some, as in the USA, Spain and the Netherlands, are actively involved in project development. Deregulation in the electricity industry is likely to have an impact on PV deployment and further measures may be necessary to increase the attractiveness of PV. As an example of such ‘measures’: a dual inverter, coupled with storage, has been introduced to make PV a grid-connected UPS system. Concerns regarding Year 2000 compliance caused a surge of sales during 1999, providing a real, grid-connect market (without subsidies) for such systems.

- Many countries (Germany, Finland, France, Italy, Japan, the Netherlands and the USA) have set targets to increase PV deployment dramatically in the near/ medium term; this can be attributed in part to the Kyoto Protocol of 1997.

Annex A IEA - PVPS Task I

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Annex B Exchange rates

The table below lists the participating countries, corresponding ISO country and currency codes, and the exchange rates used to convert national currencies. 1999 exchange rates are generally used. For Israel all financial information was provided in USD, which is the currency used locally, by industry, for statistical purposes. No financial information was available for Portugal and Spain.

Country	ISO country code	Currency and ISO code	Exchange rate (1 USD =)
Australia	AUS	Dollar (AUD)	1.67
Austria	AUT	Schilling (ATS)	12.5
Canada	CAN	Dollar (CAD)	1.486
Denmark	DNK	Krone (DKK)	7.6
Finland	FIN	Markka (FIM)	5.92
France	FRA	Franc (FRF)	6.56
Germany	DEU	Mark (DEM)	2.1
Israel	ISR	New Israeli Shekel (NIS)	(see above)
Italy	ITA	Lira (ITL)	2 000
Japan	JPN	Yen (JPY)	107
Korea	KOR	Won (KRW)	1 188
Mexico	MEX	Peso (MXP)	9.44
Netherlands	NLD	Guilder (NLG)	1.27
Norway	NOR	Krone (NOK)	8.75
Portugal	PRT	Escudo (PTE)	
Spain	ESP	Peseta (ESP)	
Sweden	SWE	Krona (SEK)	8.267
Switzerland	CHE	Franc (CHF)	1.5
United Kingdom	GBR	Sterling (GBP)	0.625
United States	USA	Dollar (USD)	1
European Union		Euro (EUR)	1